

Distribution of Benthic Foraminifera within Oxygen Minima Zone, off Central West Coast, India

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ABSTRACT

A total of 128 surface sediment samples [76 grab and 52 core top samples] were analyzed for benthic foraminiferal contents from the region off Goa in the eastern Arabian Sea upto a water depth of 3300 m. 195 species of benthic foraminifera were identified. Species belonging to *Bolivina*, *Cassidulina*, *Lernella*, *Uvigerina* and *Eponides* were found to be the most abundant within the depth zone of 150 to 1500 m - a zone considered to be Oxygen Minima Zone (OMZ) for Arabian Sea. Comparison of benthic foraminiferal species abundance in OMZ of Arabian Sea with other parts of the world oceans reveals some interesting facts. *Bulimina marginata*, which has been reported to be present in considerable number within the OMZ in other regions of the world oceans, accounted for only about 2% of the total benthic foraminifera population in the present area. On the contrary, *Bulimina costata* constituted more than 15% of the total foraminifera, which has not been reported to be abundant from OMZ of any other region of the world. This study confirms the presence of characteristic nature of the oxygen minima zone in the eastern Arabian Sea.

INTRODUCTION

There has been a considerable interest about nature and extent of Oxygen Minima Zones (OMZs) in the oceans of the world. Except for their importance as a zone supporting some peculiar type of fauna and flora, they are important from paleoceanographic point of view also, as change in climatic pattern leads to changes in nature and depth of OMZ. Such changes and fluctuations in OMZ, if documented accurately, can be used as viable proxy for paleoclimatic reconstructions. OMZ of past can be deciphered, if we know the characteristics of such zones. This can be achieved by studying the present day OMZs in the world oceans. As only few organisms, like foraminifera, can survive in the OMZ, so the presence of such particular organisms can be used as an indicator of OMZ. Though foraminiferal distribution in many OMZ from the world ocean has been studied (*for review Sen Gupta and Bernhard, 1999*), no such attempts were made

for OMZ of either Arabian Sea or Bay of Bengal. Therefore, there is a scope to fill this gap. With this objective, we carried out the identification of characteristic species of benthic foraminifera from the OMZ of the eastern Arabian Sea and a comparison is made with that of OMZs of world oceans.

ENVIRONMENTAL SETTING

The study area was selected as the eastern Arabian Sea off Goa (Fig. 1). The coastal region is bordered landward by the coastal mountains known as the "Western Ghats", extending in a roughly north-south direction with a width of 50-60 km. They are composed of Precambrian gneisses, schists, granites and charnockites covered by extensive laterite capping and rich iron ore deposits. The coastal plain is narrow and dunes of Recent age dot the entire coastline and alluvium in the river valleys (Oertel, 1958). The climate is tropical, with the Western Ghat

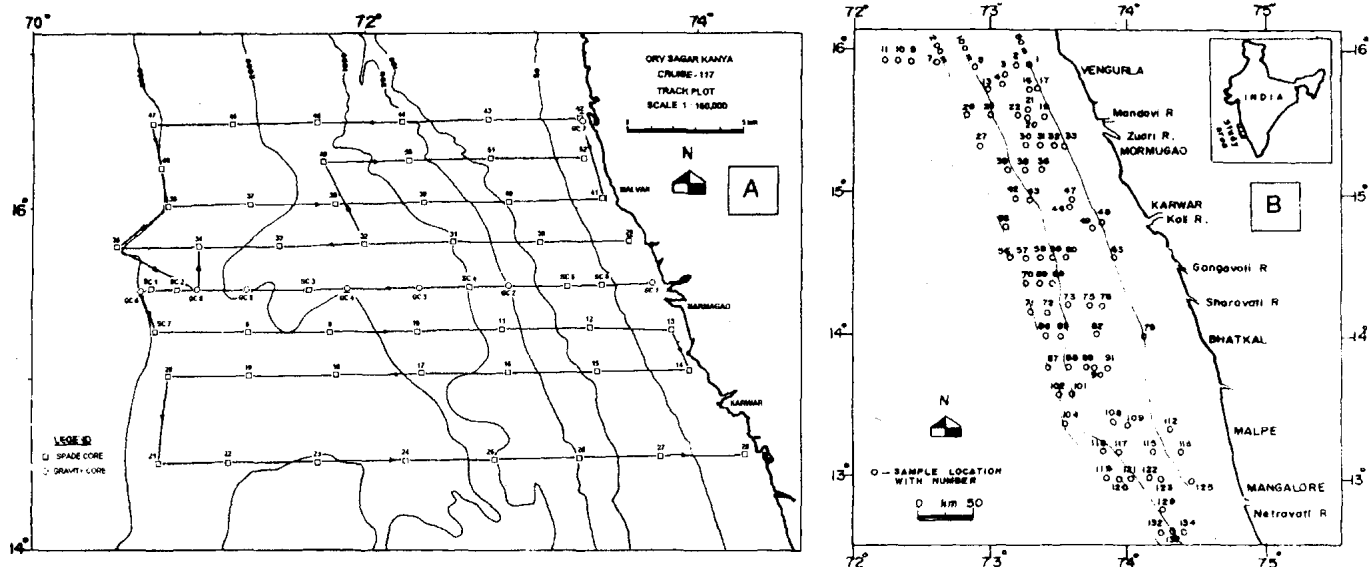


Fig.-1. Sample location maps off central West Coast (A) 52 core top samples (B) 76 tops of grab samples.

playing a prominent role in governing the coastal climate. The south-west monsoon generally breaks towards the end of May and continues for three to four months. From June upto September whole of the western region receives heavy rainfall. The seasonal heavy precipitation is carried into the Arabian Sea through numerous streams and rivers along the central west coast of India.

The Arabian Sea is located between Africa and India, covering an area of 3,863,000 sq.km, having a mean depth of 2734 m (Groves and Hunt, 1980). Over the Arabian Sea region, surface temperature ranges from 22.4°C to 28.5°C with a distinct increase from north to south (Qasim, 1982). The average salinity values for the Arabian Sea are 34-37‰ (Panikkar and Jayaraman, 1966). The dissolved oxygen content in the waters of the continental shelf indicates that the shelf waters are well oxygenated up to a depth of about 150 m, while the waters in the slope region are depleted in their dissolved oxygen content. These low oxygenated waters (<0.5 ml/l) extend up to a depth of approximately 1500 m (Reddy and Shankaranarayanan, 1968; Sharma, 1968; Stackelberg, 1972; Rao *et al.*, 1978; Sen Gupta *et al.*, 1980).

METHODOLOGY

The eastern Arabian Sea off Goa (within the

latitudes 16°29'N and 14°27'N; the longitudes 74°15'E and 70°32'E) has been chosen as the study area (Fig. 1A). Core tops of 52 spade-core samples from the water-depth of 15 m to 3300 m were processed and analyzed to study the effect of oxygen minima zone on benthic foraminiferal habitat. Benthic foraminifera were studied upto specific level of identification. However, to get a better picture, and keeping in mind that oxygen minima zone in the Arabian Sea ranges in depth from ~150 m to 1500 m, 76 more surface samples were taken at close intervals from the water depth of 44 m to 1330 m (Fig. 1B).

The total 128 surface samples were first dried overnight at ~60°C. The dried samples were then soaked with water, which was decanted several times, and lastly filled with distilled water. 10 ml of 10% sodium hexametaphosphate and then 5 ml of 15% hydrogen peroxide were added to each of the samples to remove the clay materials and the organic matters respectively. After that the samples were washed over 63 μ sieve with distilled water. The >63μ material was dried at ~60°C. Out of the dried material, a representative fraction was taken by coning and quartering for picking of foraminifera. 300-500 specimens of benthic foraminifera were picked and then identified upto species level.



Fig.-2. Scanning Electron Microphotographs of (A) *Bulimina costata* d'Orbigny (B) *Bulimina marginata* d'Orbigny.

RESULT

In the present study, a total of 195 benthic foraminiferal species (Table-1) were identified from this region. However, among the prominent species present in the OMZ of the Arabian Sea, percentage of *Bulimina costata* (Fig. 2A) averages about 15%, reaching upto 41.67% at one location, whereas the species *Bulimina marginata* (Fig. 2B) has an average percentage of 2%, maximum being 21.35% at one place. Along with *Bulimina costata*, the other index species present within OMZ are *Bolivina amygdalaeformis*, *B. durandi*, *B. kuriani*, *B. persiensis*, *B. robusta*, *B. seminuda*, *B. spathulata*, *B. spinescens*; *Cassidulina carinata*, *C. laevigata*, *C. minuta*, *C. teretis*; *Lernella* of. *L. inflata*; *Uvigerina* off. *U. peregrina*, *Uvigerina* aff. *U. schwageri*, *U. asperula*, *U. auberiana*, *U. mediterranea*; *Eponides berthelotianus*, *E. regularis*, *E. repandus*, *E. tenerus*, *E. tumidulus*,

DISCUSSION

As dissolved oxygen decreases from the surface to relatively low values in a zone at intermediate water depth, called oxygen minimum zone, which has a geographical importance because of the formation of organic-rich sediments through reduced oxidation (Kennett, 1982). Due to this geological importance it is utmost necessary to have

proxies for locating such zones in past. Proxies can be developed by studying the response of microorganism in known areas having well-developed OMZ. Among microorganism, foraminifera being extremely sensitive to environment are most viable tool to locate the presence of such zone. Kaiho (1994), after summarizing the data from all the major watermasses around the world found 21 benthic foraminiferal species characteristic of dysoxic environment (0.1-0.3 mL/L). Out of these *Bolivina robusta*, *B. seminuda*, *Bulimina exilis*, *Chilostomella oolina*, *C. ovoidea* and *Globobulimina affinis* were found to be important species in the OMZ of present area. He also reported several species from suboxic zone (0.3-1.5 mL/L) out of which only two species, namely *Bulimina aculeata* and *Melonis barleanum* are reported from the OMZ of the present area. Later, Sen Gupta and Bernhard (1999) have noted that the genera *Ammonia parkinsoniana*, *Bolivina albatrossi*, *Bulimina marginata*, *Buliminella tenuata*, *Cassidulina* sp., *Chilostomella ovoidea*, *Eponides* sp., *Gavelinopsis translucent*, *Globobulimina pacifica*, *Lernella* sp., *Nonionella stella*, *Nonionellina labradorica*, *Spiroplectammina earlandi*, *Stainforthia fusiformis*, *Trochammina pacifica* and *Uvigerina* sp. are the conspicuous benthic foraminiferal species reported from OMZ all over the world. These reports along with latest publications on this aspects bring out the fact that from Arabian Sea, only the area off Oman (Gooday *et al*, 2000) and off Pakistan area (Dulk *et al*, 1998; Jannink *et al*, 1998; Dulk *et al*, 2000) have been studied for their benthic species from OMZs so far ; whereas no such report is available either from the eastern Arabian Sea (off west coast of India) or from Bay of Bengal (off east coast of India).

This is the first such attempt of the benthic foraminiferal distribution from off central west coast of India. A review of the world ocean reveals that the diversity of the benthic species is low in OMZ as compared to above and below this zone (Gooday *et al.*, 2000), as observed in our region also. In addition to this it is noticed that *Bulimina marginata*, along with *Bolivina*, *Cassidulina*, *Lernella*, *Uvigerina* and *Eponides* are abundant benthic foraminiferal species

Table-I. Check-list of benthic foraminiferal species,

1. *Ammodiscus tenuis* Brady
2. *Ammomassilina alveoliniformis* (Millett)
3. *Ammonia sobrina* (Schupak)
4. *Ammonia tepida* (Cushman)
5. *Ammoscalaria pseudospiralis* (Williamson)
6. *Amphicoryna scalaris* (Batsch)
7. *Amphicoryna separans* (Brady)
8. *Amphistegina radiata* (Fichtel and Moll)
9. *Articulina* sp.
10. *Asterorotalia dentata* (Parker and Jones)
11. *Asterorotalia inflata* (Millett)
12. *Baggina phillipinensis* (Cushman)
13. *Bolivina alata* (Seguenza)
14. *Bolivina amygdalaeformis* Brady
15. *Bolivina* of. *B. subspathulata* (Boomgaard)
16. *Bolivina durandii* Millet
17. *Bolivina kuriani* Seibold
18. *Bolivina persiensis* Lutze
19. *Bolivina robusta* Brady
20. *Bolivina seminuda* Cushman
21. *Bolivina* sp.
22. *Bolivina spathulata* (Williamson)
23. *Bolivina spinescens* Cushman
24. *Bolivina vadescens* (Cushman)
25. *Bolivina variabilis* (Williamson)
26. *Bolivinellina translucens* (Phleger and Parker)
27. *Bolivinina subangularis* (Brady)
28. *Borelis* sp.
29. *Brizalina siriatala* (Cushman)
30. *Bulimina aculeata* d'Orbigny
31. *Bulimina* of. *B. pupoides* d'Orbigny
32. *Bulimina costata* d'Orbigny
33. *Bulimina exilis* (Brady)
34. *Bulimina marginata* d'Orbigny
35. *Caneris auricula* (Fichtel and Moll)
36. *Caneris indicus* (Cushman)
37. *Caneris oblonga* (Williamson)
38. *Caribbeanella* sp.
39. *Cassidulina carinata* Silvestri
40. *Cassidulina laevigata* d'Orbigny
41. *Cassidulina minuta* Cushman
42. *Cassidulina teretis* Tappan
43. *Chilostomella oolina* Schwager
44. *Chilostomella ovoidea* Reuss
45. *Cibicides lobatulus* (Walker and Jacob)
46. *Cibicides margaritifera* (Brady)
47. *Cibicides refulgens* Montfort
48. *Cibicides subhaidingerii* Parr
49. *Cornuspira involvens* (Reuss)
50. *Dentalina* aff. *D. protumida* (Schwager)
51. *Dentalina* sp.
52. *Discorbinella bertholothi* (d'Orbigny)
53. *Discorbinella* sp.
54. *Edentostomina rupertiana* (Brady)
55. *Ehrenbergina serrata* Reuss
56. *Elphidium advenum* Cushman
57. *Elphidium* aff. *E. selyense* (Heron-Earland)
58. *Elphidium craticulatum* Fichtel and Moll
59. *Elphidium crispum* Linne
60. *Elphidium discoidale* d'Orbigny
61. *Epistominella naraensis* (Kuwano)
62. *Eponides berthelotianus* (d'Orbigny)
63. *Eponides regularis* Phleger and Parker
64. *Eponides repandus* (Fichtel and Moll)
65. *Eponides tenerus* (Brady)
66. *Eponides tumidulus* (Brady)
67. *Favulina hexagona* (Williamson)
68. *Fissurina* of. *F. annectens* (Burrows and Holland)
69. *Fissurina cucullata* Silvestri
70. *Fissurina lucida* (Williamson)
71. *Fissurina* sp.
72. *Fursenkoina pauciloculata* (Brady)
73. *Fursenkoina pontoni* (Cushman)
74. *Fursenkoina* sp.
75. *Gaudriya* sp.
76. *Gavelinopsis* sp.
77. *Geminospira bradyi* Bermudez
78. *Globobulimina* of. *G. affinis* (d'Orbigny)
79. *Globobulimina perversa* (Cushman)
80. *Globocassidulina subglobosa* (Brady)
81. *Grigelis guttifera* (d'Orbigny)
82. *Gyroidina orbicularis* d'Orbigny
83. *Hemirobulina altifrons* (Parr)
84. *Hopkinsinella glabra* (Millett)
85. *Hyalinea balthica* (Schroter)
86. *Hyalinonetron sahulense* Patterson and Richardson
87. *Islandiella* sp.
88. *Karrerella* sp.
89. *Laevidentalina* aff. *L. aphelis* Loeblich and Tappan
90. *Laevidentalina* aff. *L. subemaciata* (Parr)
91. *Laevidentalina communis* d'Orbigny
92. *Laevidentalina subsoluta* (Cushman)
93. *Lagena laevis* (Montagu)
94. *Lagena* sp. A
95. *Lagena* sp. B
96. *Lagena striata* (d'Orbigny)
97. *Lagenosolenis* aff. *L. soulei* McCulloch

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98. *Lamarckina ventricosa* (Brady)
 99. *Lernella* of *L. inflata* (Le Roy)
 100. *Lenticulina calcar* (Linnaeus)
 101. *Lenticulina convergens* (Bornemann)
 102. *Lenticulina orbicularis* (d'Orbigny)
 103. *Lenticulina reniformis* (d'Orbigny)
 104. *Melonis barleanum* Williamson
 105. *Mesolenticulina partidiana* McCulloch
 106. *Miliolinella australis* (Parr)
 107. *Miliolinella subrotunda* (Montagu)
 108. *Neolenticulina chathamensis* McCulloch
 109. *Neolenticulina peregrina* (Schwager)
 110. *Neouvigerina ampullacea* (Brady)
 111. *Nodosaria ambigua* Neugeboren
 112. *Nodosaria catesbyi* d'Orbigny
 113. *Nodosaria intercellularis* Brady
 114. *Nodosaria pauciloculata* Cushman
 115. *Nodosaria scalaris* (Batsch)
 116. *Nodosaria* sp.
 117. *Nonion asterizans* (Fichtel and Moll)
 118. *Nonion incisum* (Cushman)
 119. *Nonion scaphum* (Fichtel and Moll)
 120. *Nonionella auris* d'Orbigny
 121. *Nonionella hantkeni* (Cushman and Applin)
 122. *Nonionella opima* Cushman
 123. *Nonionella pulchella* Hada
 124. *Nonionella* sp.
 125. *Nonionella stella* Cushman and Meyer
 126. *Nonionoides boueanum* (d'Orbigny)
 127. *Nonionoides elongatum* (d'Orbigny)
 128. *Nonionoides grateloupi* d'Orbigny
 129. *Operculina granulosa* Leymerie
 130. *Pararotalia* sp.
 131. *Peneroplis planatus* (Fichtel and Moll)
 132. *Planorbulinella larvata* (Parker and Jones)
 133. *Procerolagena gracilis* (Williamson)
 134. *Pseudoepionides pauciloculata* (Phleger and Parker)
 135. *Pseudohauerina orientalis* (Cushman)
 136. *Pygmaeosestron hispidula* (Cushman)
 137. *Pyrgo fornasinii* Chapman and Parr
 138. *Pyrgo laevis* DeFrance
 139. *Pyrgoella dokici* (Pavlovic)
 140. *Quinqueloculina berthelotiana* d'Orbigny
 141. *Quinqueloculina* of *Q. elegans* d'Orbigny
 142. *Quinqueloculina* of *Q. intricata* Terquem
 143. *Quinqueloculina echinata* (d'Orbigny)
 144. *Quinqueloculina kerimbatica* (Heron Allen and Earland)
 145. *Quinqueloculina laevigata* d'Orbigny
 146. *Quinqueloculina lamarckiana* d'Orbigny
 147. *Quinqueloculina oblonga* (Montagu)
 148. *Quinqueloculina pseudoreticulata* Parr
 149. *Quinqueloculina reticulata* d'Orbigny
 150. *Quinqueloculina seminulum* (Linne)
 151. *Quinqueloculina trigonula* Terquem
 152. *Quinqueloculina undulosa costata* Terquem
 153. *Quinqueloculina vulgaris* d'Orbigny
 154. *Reophax scorpiurus* Montfort
 155. *Reussella simplex* (Cushman)
 156. *Rosalina* sp.
 157. *Rotalidium annectens* Parker and Jones
 158. *Sagrinella* aff. *S. guinai* Saidova
 159. *Sigmoilinita tenuis* (Czjzek)
 160. *Siphogenerina* sp.
 161. *Siphogenerina virgula* (Brady)
 162. *Siphonaperta horrida* (Cushman)
 163. *Siphonaperta minuta* (Collins)
 164. *Siphonaperta* sp.
 165. *Siphouvigerina porrecta* (Brady)
 166. *Spirillina* sp.
 167. *Spiroloculina aequa* Cushman
 168. *Spiroloculina antillarum* d'Orbigny
 169. *Spiroloculina communis* Cushman and Todd
 170. *Spiroloculina depressa* d'Orbigny
 171. *Spiroloculina indica* Cushman and Todd
 172. *Spirophthalmidium acutimargo* (Brady)
 173. *Spirophthalmidium* sp.
 174. *Spirotextularia fistulosa* (Brady)
 175. *Takayanagia delicata* (Cushman)
 176. *Textularia agglutinans* d'Orbigny
 177. *Textularia conica* d'Orbigny
 178. *Trifarina bradyi* Cushman
 179. *Trifarina carinata* (Cushman)
 180. *Triloculina* of *T. affinis* d'Orbigny
 181. *Triloculina insignis* (Brady)
 182. *Triloculina* sp. A
 183. *Triloculina* sp. B
 184. *Triloculina terquemiana* (Brady)
 185. *Triloculina tricarinata* d'Orbigny
 186. *Trochammina* of *T. inflata* (Montagu)
 187. *Uvigerina* aff. *U. peregrina* Cushman
 188. *Uvigerina* aff. *U. schwageri* Brady
 189. *Uvigerina asperula* Czjzek
 190. *Uvigerina auberiana* d'Orbigny
 191. *Uvigerina mediterranea* Hofkar
 192. *Uvigerina* sp.
 193. *Vaginulina patens* Brady
 194. *Valvobifarina* sp.
 195. *Virgulinita pertusa* (Reuss)

in oxygen-depleted environment from many regions of the world. But in the present study area though the above assemblage is present, the percentage of *Bulimina marginata* is very less. On the contrary, the percentage of *Bulimina costata* is very high, whereas it has not been reported as an index fauna from the oxygen minima zone of other regions around the world. Therefore, it is proposed that *Bulimina costata* may be considered as an indicator of OMZ in eastern Arabian Sea.

ACKNOWLEDGEMENTS

The authors express thanks to Dr. E. Desa, Director, National Institute of Oceanography for his permission to publish the results. The authors are also thankful to Mr. Rajeev Saraswat for his help for reviewing the manuscript critically. One of the authors (A.M.) acknowledges the Council of Scientific and Industrial Research, New Delhi [CSIR-JRF fellowship no.2-40/99 (i) -E.U.II] for financial support.

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